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**DISTRIBUTED-PROCESSING SIMULATOR
FINAL REPORT**

BY IVAN LA-GARDE

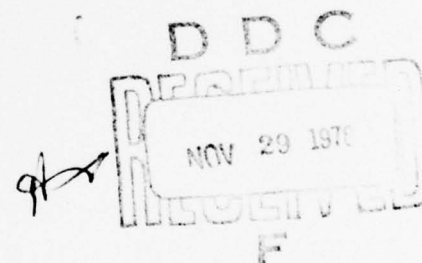
OCTOBER 1978

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Prepared for

DEPUTY FOR DEVELOPMENT PLANS

ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
Hanscom Air Force Base, Massachusetts



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ABSTRACT (Continue on reverse side if necessary and identify by block number) During fiscal 1977, IR&D Project 9490 was established for the design and construction of a radar simulator whose system design was based on distributed-processing principles. The project scope was limited to the basic system control elements and one of the video generation modules. This document provides an overview report on the background to the project, the work accomplished, and the results obtained.			

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Several members of D-82 contributed to the design and construction of the radar simulator. They, and their principal responsibilities, were as follows:

Paul Buote	Target Generator Software
Glenn L. Glatfelter	AN/UPA-35 Radar Display
Victor Kross	Target Generator Module
Robert J. Leyman	System Clock
John E. Roberts	Supervisory Network and Its Software

Principal technician support was provided by Elliott H. Gelin and Romolo M. Citro.

Ivan La-Garde was the project leader.

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EXECUTIVE SUMMARY

During FY 1977, IR&D Project 9490, entitled "Distributed-Processing Simulator," was authorized to design and fabricate portions of a radar simulator. This document reports the background and objectives associated with the project, and records the accomplishments and conclusions produced under this effort.

The Distributed-Processing Simulator was patterned after a simulator specification for the 485A program, which is responsible for Tactical Air Control System (TACS) improvements. The simulator required by this program is intended for training personnel at Control and Reporting Centers or Posts, and simulates an air surveillance radar.

The Distributed-Processing Simulator project was an outgrowth of earlier work supported by Technology Base funding and directed towards the exploitation of low-cost electronics. Objectives in establishing the simulator project were to utilize low-cost electronics, demonstrate that distributed processing could lead to lower cost, and gain some experience with distributed-processing architecture.

The equipment designed and fabricated under this project provided the critical parts of a simulator which produces a standard Plan Position Indicator (PPI) display associated with an air surveillance radar. The system requirement is relatively complex and demanding; some 200 "aircraft" are kept under surveillance with the display always properly reflecting the simulated scenario. Modification of the aircraft parameters is permissible at any time, initiated by either man or machine.

The simulator consists of a supervisory network which provides system control and the man-machine interface, a target generator module which generates target (aircraft) video, and a standard radar-type PPI display. System references related to pulse repetition frequency (PRF), antenna angle (bearing), and scenario time are also provided.

The project made extensive use of low-cost Large Scale Integrated electronics, including RAM's (random access memory), ROM's (read-only memories), the most recently available logic types of integrated circuits, and a relatively new microprocessor, the TMS-9900.

Interest in exploring ways to reduce development cost was based on two lines of argument: (1) that development time or manpower is more influential on cost than hardware, and (2) that distributed processing

offers an opportunity to partition a project and permit parallel — but more importantly — independent design activities. Proper partitioning allows the designers to assign plenty of "hardware and software space" to critical areas of the system, and thereby avoids the time-consuming and error-provoking optimization usually encountered in constrained centralized architectures. As a result, our design activity proceeded in a straightforward manner, with no complications requiring extra development time or difficult solutions. Because the design and implementation of the modules and system software did indeed proceed smoothly and in parallel, and because system integration and test was almost trivial, we conclude that the potential cost benefits of distributed processing can be substantial. Our experience re-emphasized the importance of fully exploring the system architecture before module and software design begins.

In operational terms, the project resulted in a small system which did everything that was expected of it, and the quality of the radar responses presented on the PPI display was judged "very satisfactory" by experienced observers.

The report concludes with reference to some of the possible avenues along which this initial effort could be extended; they include other forms of radars, and explorations of ECM/ECCM relationships in both radar and communication systems.



M23-718

This photo shows the equipment designed and built under the 9490 Project. At the left is the PPI display (AN/UPA-35 loaned to the project); at the center is the rack containing the Target Generator and the Supervisory Minicomputer; and located on the table is the CRT/Keyboard Terminal which provided the man-machine interface to the system.

The photo incidentally shows some members of the design team: from left to right, Ivan La-Garde, Paul Buote, and Victor Kross.

ACRONYMS/ABBREVIATIONS

USED IN THIS REPORT

A/C	Aircraft
AZ	Azimuth
CPU	Central Processor Unit
CRT	Cathode Ray Tube
EPROM	Electrically Programmable ROM
I/O	Input/Output
PPI	Plan Position Indicator
PPS	Pulses per Second
PRF	Pulse Repetition Frequency
RAM	Random Access Memory
RCS	Radar Cross-Section
ROM	Read-Only-Memory
SIF	Selective Identification Feature
SRN	Scenario Reference Number (Refers to a target)
STEM	System Trainer and Exercise Module
TGM	Target Generator Module
TTY	Teletype

SECTION I

INTRODUCTION

Background

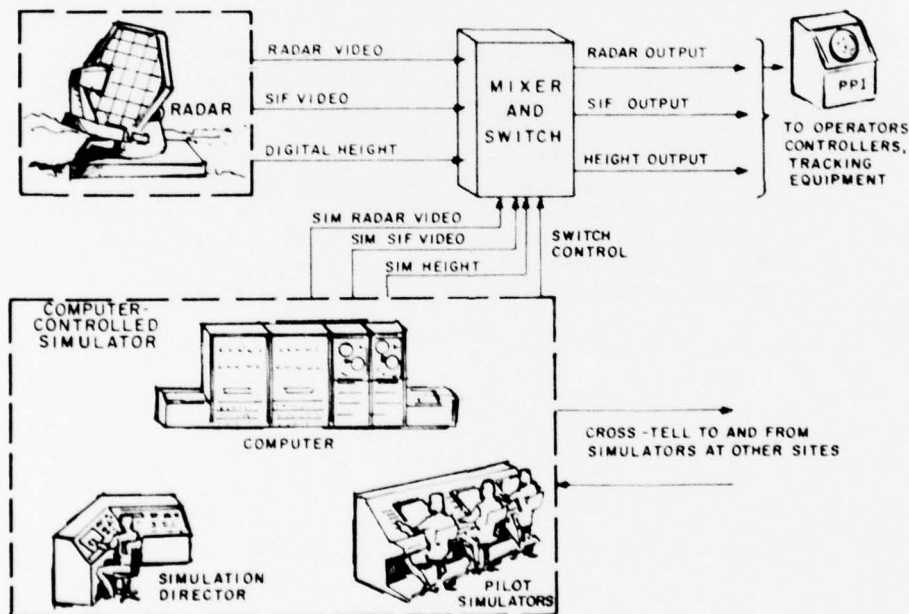
In order to introduce the Distributed-Processing Simulator project funded under IR&D account 9490, one must first understand some of the background which led up to the 9490 project.

This background started in FY76-FY77 under an Air Force Technology Base effort (Project 7010), responsible for the exploitation of Low-Cost Electronics. Under the 7010 effort we sought a system problem which would be a suitable vehicle for extending our work in low-cost electronics, and at the same time offer an opportunity to learn more about the application of distributed processing as a design technique.

The candidate system selected under the 7010 effort was a small system simulating the AN/TPS-43 air surveillance radar, with its associated display and interfaces to other surveillance centers. A requirement for such a simulator had already been established for the 485A program and the simulator was identified as STEM (System Trainer and Exercise Module). Of further interest, a recently generated specification on STEM was available and it represented a real, rather than synthetic, challenge for our investigation. The design effort aimed to meet, in principle if not in detail, the many and exacting requirements specified for the system.

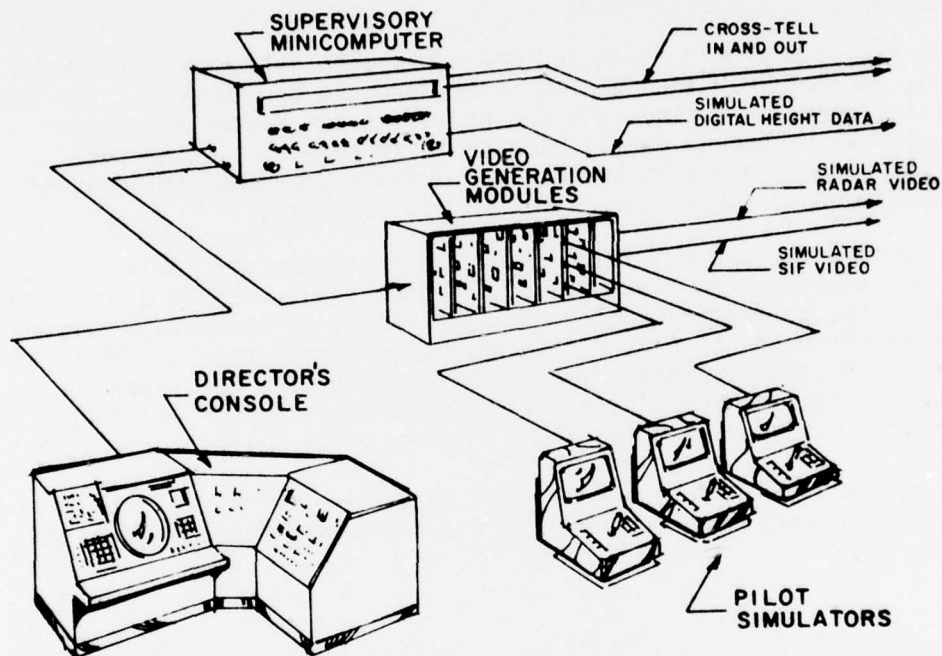
The diagram given in figure 1-1 shows the STEM system and its interconnections as defined by the specification. The major components of the system are:

- 1) an AN/TPS-43 radar, or its equivalent, which provides genuine radar video,
- 2) a computer-controlled simulator which provides synthesized radar video,
- 3) a mixer/switch unit which provides for transfer of either or both, genuine or synthetic radar video, and
- 4) a standard Plan Position Indicator (PPI) display.



VG-45791

Figure 1-1. STEM System and its Interconnections



VG-45787

Figure 1-2. Distributed-Processing Version of STEM

Figure 1-2 shows the distributed-processing version of a computer-controlled radar simulator patterned after the STEM requirement. This concept was established under the Project 7010 effort and the principal components are:

- 1) a bank of video generation modules to generate the radar video,
- 2) a supervisory minicomputer to control the operation of the video generation modules,
- 3) a bank of pilot simulators for simulating certain aircraft and their human control interface, and
- 4) a director's console which permits control and observation of the system operation.

Project 7010 Hardware Design

With a system problem selected and a proposed system design agreed upon, project 7010 then started some hardware development. For the initial detailed engineering design effort the Target Generator Module was selected, partly because it appeared to be the most challenging, and partly because its outputs are required by other modules within the system.

By April 1977, project 7010 efforts on the radar simulator produced a conceptual system block diagram (figure 1-4), a block diagram for the target generator module, and some pieces of hardware which met the requirements of part of the target generator module. This hardware formed an assembly identified as the Antenna Scan Modulator, and coupled with it were a single video generator channel and deflection circuits designed to drive a PPI display (Plan-Position Indicator).

The system block diagram — a paper design — and these few pieces of hardware formed the platform from which project 9490 was launched in May 1977.

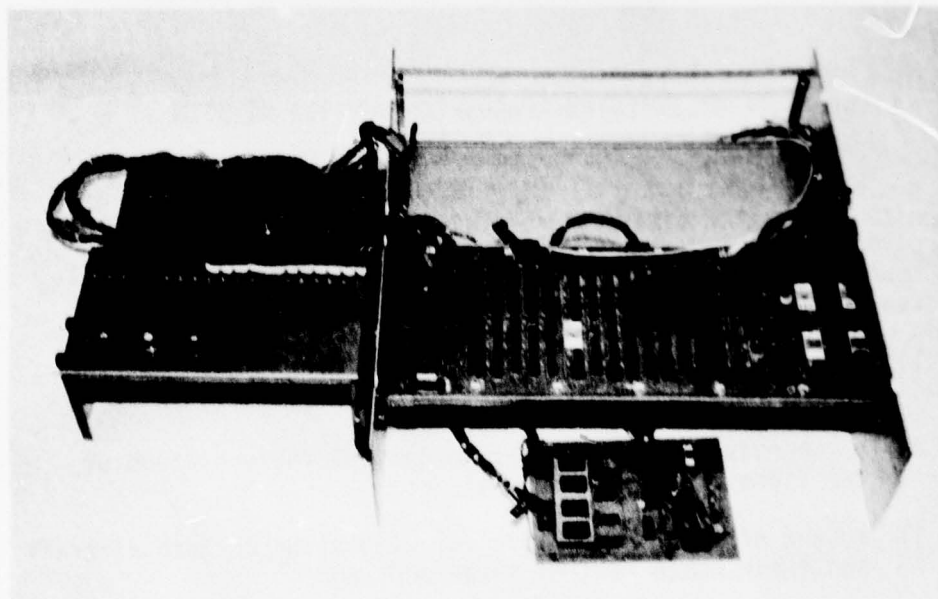


Figure 1-3. Simulator Hardware Produced under Project 7010

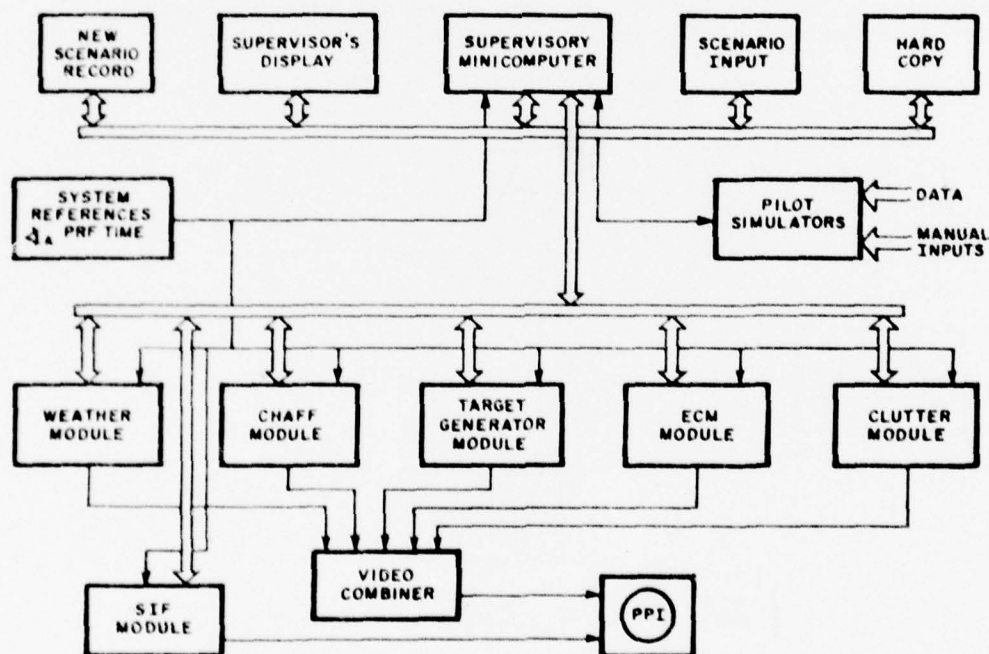
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The 9490 Project

Figure 1-4 shows the system block diagram of the distributed-processing version of the STEM simulator conceived under the project 7010 effort.

The top layer of blocks provides the supervisory network which consists of the supervisory minicomputer and its associated peripherals. Within this group, the block labeled "Supervisors Display" represents the Director's Console shown in figure 1-2.

The various video generation modules are shown feeding the Video Combiner, and the Selective Identification Function (SIF) Module feeds directly to the PPI since that signal is processed through a separate receiver.



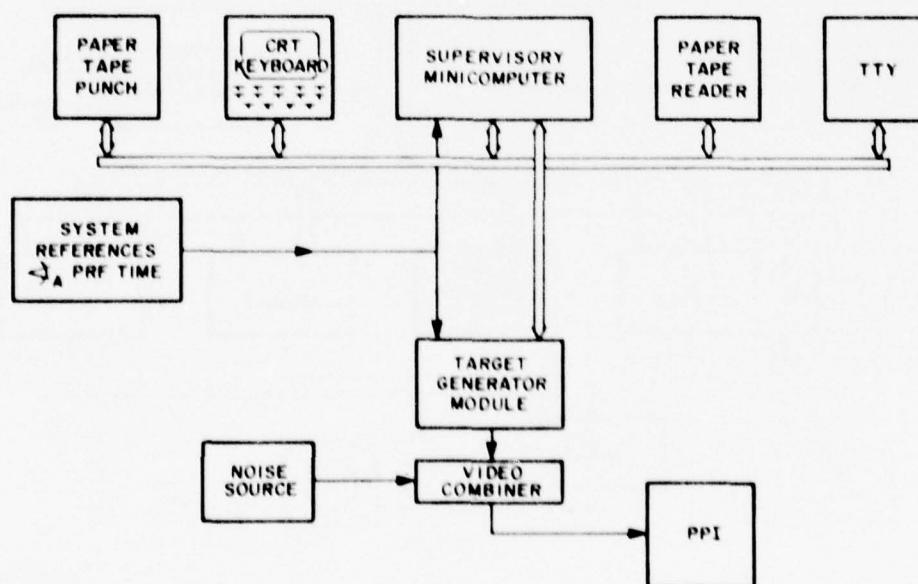
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Figure 1-4. System Block Diagram, Distributed-Processing Version of STEM

There was not sufficient funding available to support a full development program and therefore project 9490 efforts were directed towards a limited version of the system; figure 1-5 shows the project 9490 version of the distributed-processing simulator. Only the critically important elements received detailed attention; these were:

- system engineering, represented by the supervisory network and the communication arrangements
- system references, which are necessary for the system to operate
- the Target Generator module, and
- the PPI display.

The equipment which was produced under this project met the task objectives of providing MITRE with experience in distributed-processing design, demonstrating some characteristics critical to a realistic radar simulation, and providing a system which would gracefully accept system growth.



VG 45774

Figure 1-5. Project 9490 Version of Distributed-Processing STEM



M36-705

Figure 1-6. This photo shows the equipment designed and built under Project 9490. Not shown is the AN/UPA-35 PPI display which became available late in the project schedule. The modified xy display shown in the equipment rack served as the PPI display during most of the project development.

SECTION II

THE 9490 SIMULATOR

The IR&D Project 9490 was established with several objectives:

- 1) to provide some experience in designing a system utilizing distributed processing techniques. We were interested in:
 - architecture and its impact on module design,
 - possible problems in module-level and system-level testing,
 - possible problems in system integration,
 - the inefficient use of hardware and its impact on the module design, and
- 2) to demonstrate our initial belief that distributed processing, as a design technique, offers an opportunity to reduce system cost, reduce development time, and provide system flexibility.
- 3) to build an equipment which could be used as a base for further work in either distributed processing or simulators.

The Project 9490 Simulator was patterned after the complete system defined under the earlier phase funded by Project 7010, Low-Cost Electronics, and the system block diagram is shown in figure 2-1.

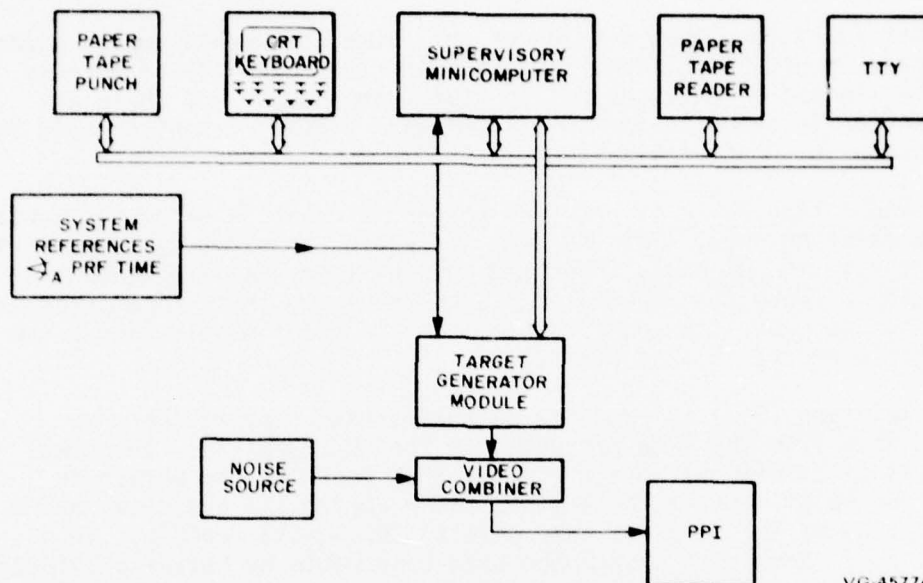
The equipment consists of:

- a supervisory network which provides in equivalent form all the functions called for in the complete design.
- a set of system references which define antenna angle rate, radar PRF, and scenario time.
- the Target Generator module which satisfies all of the requirements set by the full-system design.
- a video combiner and noise source which are a minimum equivalent of this function in the full-system design.
- a PPI display — the AN/UPA-35.

An important part of the simulator design also concerned the bus structure and message structure between the Supervisory Minicomputer and the video generation modules.

Supervisory Network

Five major functions are provided within the Supervisory Network and they are described in the following paragraphs.



VG-45774

Figure 2-1. Project 9490 Version of the Radar Simulator

The Supervisory Minicomputer, as its name implies, is primarily responsible for supervision and control of the simulator operations, as distinct from doing the many real-time computations which are done in the video generation modules. Some computation is done within the Supervisory Minicomputer, and this is the conversion of inputs expressed in Standard Air Force units (range, azimuth, heading, velocity, height) to units suited to the design of the Target Generator and other video generation modules (position in x, y, z; velocity in x, y, z; and acceleration in x, y, z).

The CRT/Keyboard Terminal provides the functions required of the Simulation Director's Console; these are basically intended to permit manually initiated aircraft flights, modify any of the aircraft flight patterns within the simulator, or permit the input of stored data to control aircraft flight patterns. The CRT/Keyboard Terminal is also able to interrogate either the Supervisory Minicomputer or the video generation modules to determine the status, at any time, of the scenario being simulated.

The Paper Tape Reader satisfies the functional requirement to permit preprogrammed scenarios to be utilized in the system. One may utilize the preprogrammed capability to simply establish an initial scenario, or one may have a complete scenario development stored on paper tape and have it played out through the simulator.

A more fully developed version of this simulator would employ magnetic records to establish scenarios, and since the quantity of data is quite limited — only changes in status are noted, and these are expressed in symbolic terms — a standard digital cassette would be adequate for most applications.

The Paper Tape Punch is provided to permit creation of new scenarios from existing ones. This is done by feeding an existing scenario to the system and manually inputting changes from the CRT/Keyboard Terminal. Resulting control messages issued by the minicomputer are fed to the paper tape punch as well as the video modules and a new scenario record is thus created.

The Teletype (TTY) is provided so that a hard copy may be made available from the data presented to the CRT terminal. In normal use it is beneficial, after a simulation exercise, to permit an evaluation of some of the actions taken during the exercise, and a hard copy of the relevant data permits this quite readily. In a more fully developed system the hard copy would be better provided by equipment specifically designed for the purpose; most significantly it would have a faster writing rate, and probably be capable of also recording graphics as well as alpha-numerics.

System References

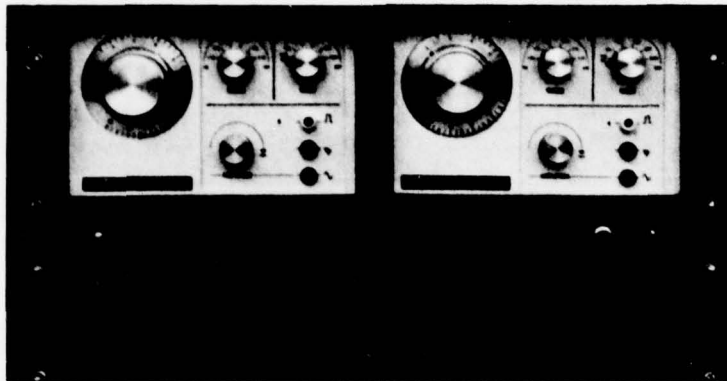
The system references required to permit operation of the simulator relate to:

- antenna position or rotation rate
- radar PRF, and
- scenario time.

Outputs from these sources are fed to the modules and supervisory minicomputer so that synchronism is maintained among the various, and otherwise independent, functions within the simulator.

Currently used standards define antenna position by a 12-bit digital word which is equivalent to one bit per 0.088 degrees. Thus an antenna rate of 6 revs/min. (typical for a search radar) would be expressed as a pulse rate of 410 pulses/second. Conversion from antenna rate to antenna position involves a simple counting arrangement and the generation of a north strobe.

As we see in figure 2-2, the antenna rate is defined by a standard pulse generator instrument. This was used so that we could emphasize the flexible nature of the simulator; although it was intended primarily to simulate a search radar with an antenna rate of (say) 6 revs/min., it is able to operate at any rate from stationary to perhaps several revs/sec.— the limit relates to target density, not to antenna rate.



M36-707

Figure 2-2. System Reference Hardware

The Radar PRF is provided by another pulse generator whose output is utilized to simulate the trigger normally available from a radar transmitter. As with the antenna rate, the simulator is flexible in terms of permitted PRF values; however, since it takes a finite time to process each of the required 200 targets, there is an upper limit to the PRF of approximately 330 pulses/sec.

The System Clock provides time information used by the various modules in the system. Since many operations are predicated on an interrupt mechanism, one-second pulses are made available to the system. Scenario time is also required for some operations and this is provided as a 16-bit number updated once per second; scenario time is also displayed on the front panel.

The system clock also has a "Faster Than Real-Time" mode of operation which is useful for speeding to some point in a scenario development, or for observing the development of a scenario at faster than normal rate.

The Target Generator Module

Inputs to the Target Generator Module consist of instructions provided by the Supervisory Minicomputer, and the various references supplied by the System Reference Group. Provided with these inputs the Target Generator Module generates video pulses as required for a PPI display. These pulses are generated in proper synchronism with the "rotating antenna" and are appropriately responsive to aircraft characteristics such as position, aspect angle, radar cross-section, and range.

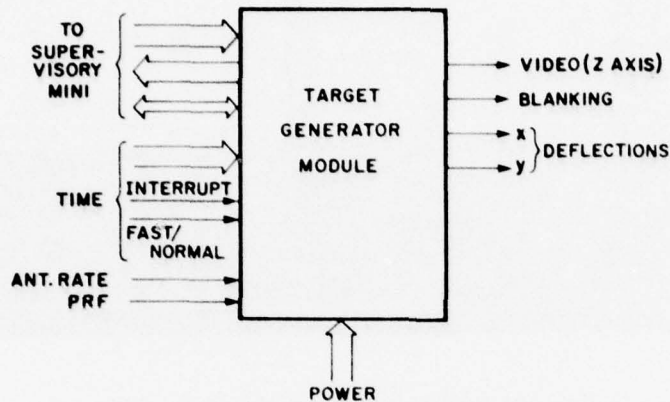


Figure 2-3. Target Generator Module Interfaces

The output of the Target Generator Module, as shown in figure 2-3, is video which is fed to the PPI z-axis. The Target Generator Module, as it was built under the 9490 project, also provided blanking and deflection signals for the PPI display; this was done as a practical convenience although these signals would not normally be regarded as part of the target generation function.

Video Combiner

The Video Combiner incorporated into this version of the radar simulator is very limited in objective; it has a transfer characteristic which soft-limits on signals greater than about 2.5 volts, and it combines the gain-compressed output with noise provided by a standard noise generator.

Plan Position Indicator (PPI)

The radar simulator makes use of two PPI displays; one is small and conveniently mounted in the equipment rack — this is a Hewlett-Packard 1300A xy display adapted for the task — the other is a standard military equipment, the AN/UPA-35. The smaller unit is useful for quick or simple system checks; the larger unit provides an excellent means of observing the simulated radar responses and provides a more accurate measure of the fine-grain performance of the simulator.

Operations and Computations

The operations and computations implemented at system level are summarized in table 2-1.

OPERATIONS	<ul style="list-style-type: none">• Initialize the system• Establish an initial scenario• Modify scenario in progress• Establish/modify, radar power and height (16 aircraft types, 5 values of radar cross-section)• Control/Interrogate modules
COMPUTATIONS	<ul style="list-style-type: none">• Convert range, azimuth, heading, velocity and height to $x, y, z, \dot{x}, \dot{y}, \dot{z}$.
OFF-LINE SCENARIO GENERATION	<ul style="list-style-type: none">• Converts latitude/longitude to $x, y, z, \dot{x}, \dot{y}, \dot{z}$.

Table 2-1. System Level Operations and Computations

The primary responsibility of the minicomputer is to accept data from one source (e.g., the scenario-tape reader) and send it to another (e.g., the target data module). Operations within the supervisory minicomputer are not done in real time but are done during the time 2 to 20 seconds prior to the real-time requirement. In addition to transferring scenario and operator commands and exercising control, the minicomputer does a little computation, principally related to the conversion of coordinates from one system to another. CPU utilization is running at only about 2%; the minicomputer generally has nothing to do, since it only responds to a scenario "event" or an operator display request. About 89% of the available memory is employed and the memory utilization is given below.

FORTRAN (14 routines)	34.9%
FORTRAN functions (sin, cos, etc.)	21.7%
Links & interrupt vectors	12.5%
FORTRAN I/O drivers	12.4%
Spare	11.1%
Tables	4.9%
Assembly language	2.5%

The freedom from real-time computing constraints makes the programming of the minicomputer a virtually trivial exercise. All calculations and data transfers can be written in non-real-time FORTRAN, and no real-time operating system of any kind is required. Furthermore, the system architecture and the module designs have focused on minimizing the amount of data to be transferred, both within the minicomputer and on the system data bus.

Communication between the Supervisory Minicomputer and the various video generation modules is done on a bus structure designed in a master-slave form; messages are fed in either direction, but the supervisory minicomputer, acting as master, always initiates and controls any message exchange. The principal message traffic on the bus consists of commands, and initial conditions sent from the master to the slaves; communication does occur in the other direction although it is done primarily to satisfy an interrogation function rather than to continually feed data back to the supervisory network. The master-slave bus arrangement is sometimes regarded as a somewhat limited link; however, the very simple communication requirements of the simulator are well-matched to the characteristics of the master-slave concept, and the simulator is consequently provided with a simple and reliable bus structure.

MASTER → SLAVE

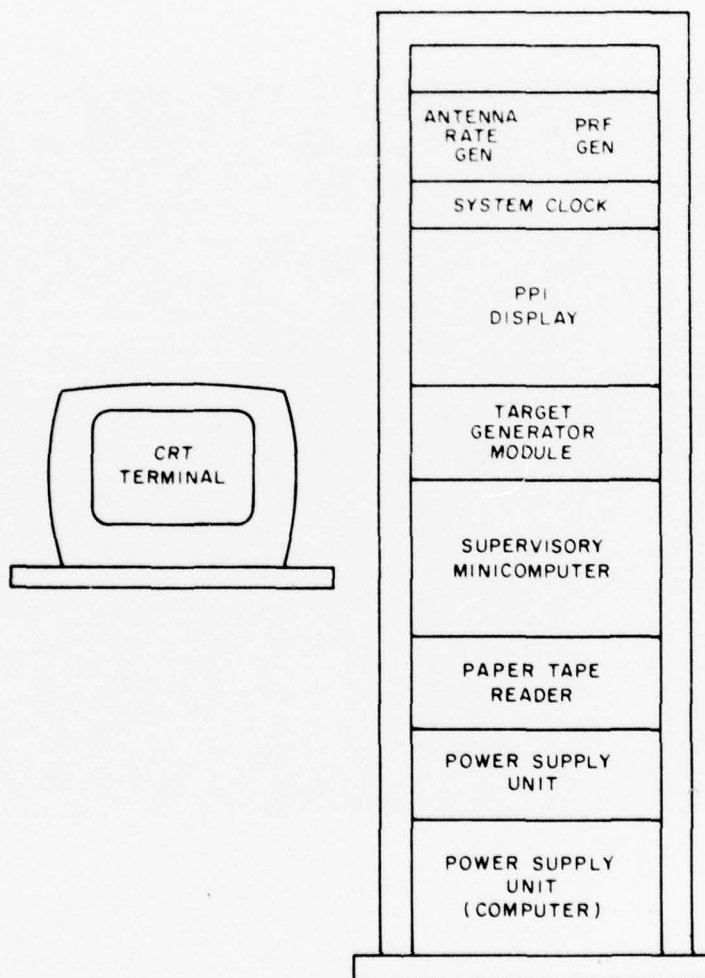
- Basic pattern, 4 words/message
- Messages define

- position	- radar cross-section
- velocity	(16 types, 5 values/type)
- acceleration	- aircraft type
- target masking	(1 Of 16)
- highlighting	- transmitter power
- radar altitude	- status requests

SLAVE → MASTER

- These messages are sent only in response to status requests from the master
 x,y,z,x,y,z

Table 2-2. Master-Slave Messages

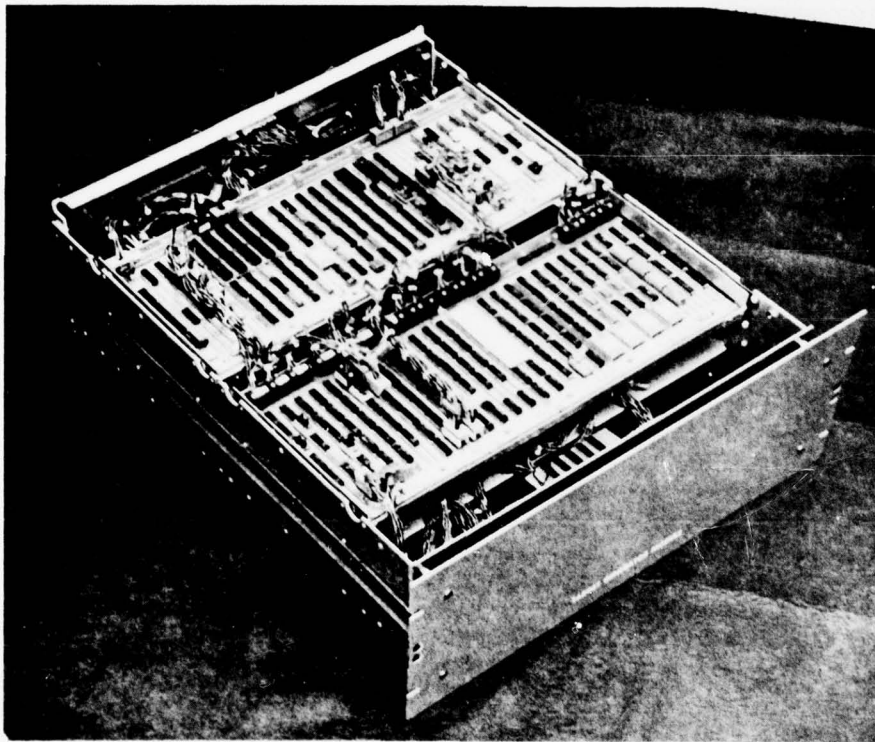


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Figure 2-4. Equipment Layout of the Project 9490 Version of the Radar Simulator

SECTION III

THE TARGET GENERATOR MODULE



M36-704

Figure 3-1. This photograph shows the Target Generator Module. It consists of 3 assemblies: the Target Processor Assembly seen at the front of the module, the Antenna Scan Modulator located behind it, and below (not visible in this photo) the Video Generator Assembly.

General Description

The Target Generator Module block diagram is given in figure 3-2. It is detailed to the level that identifies all the major functions provided in this module.

Starting at the left of the diagram, the first functional block is the I/O interface which provides the interface between the Target Generator Module and the Supervisory Minicomputer. All instructions given the Target Generator are fed in via this port from the Supervisory Minicomputer; responses to interrogations are also fed out of this port.

The next significant block is the Target Generator's microprocessor which is a Texas Instrument TMS-9900. This is a 16-bit processor operating at a clock-rate of approximately 2.5 MHz.

The peripherals supporting the microprocessor are several random access memories (RAMs), a Read-only memory and some fixed logic. RAM₁ provides temporary storage for instructions which may be fed to the Target Generator prior to the effective time for execution, RAM₂ provides storage of all target data including current position, and RAM₃ provides storage of target position expressed in radar coordinates (ρ , θ). The target table RAM provides storage for data defining average radar cross section; 16 aircraft types, each with 5 different aspect angles, may be characterized by this memory. This memory is of RAM form rather than ROM so that one may change the available patterns of radar cross section during the scenario if one wishes. The program ROM is provided solely as a development aid and is used in conjunction with a "front-panel" set of controls recessed behind the Target Generator Module front panel. The fixed logic is a set of hardware designed to convert data from linear to logarithmic form, or the reverse; this was provided because an initial estimate of the microprocessor loading concluded that valuable computation time could be saved by utilizing a hardware implementation.

The microprocessor is fed time data and antenna angle information to permit properly synchronized operation. Time expressed as a 1-second interrupt is used to initiate updating of target positions in the xy domain, and time expressed as a 16-bit binary number is used as a clock to determine when to implement actions specified for a specific point in time in the scenario. Antenna angle is used to define antenna sectors of $22\frac{1}{2}$ degrees, and conversion of target position data from xy form to $\rho\theta$ form is done in blocks (or sectors) on an "as needed" basis.

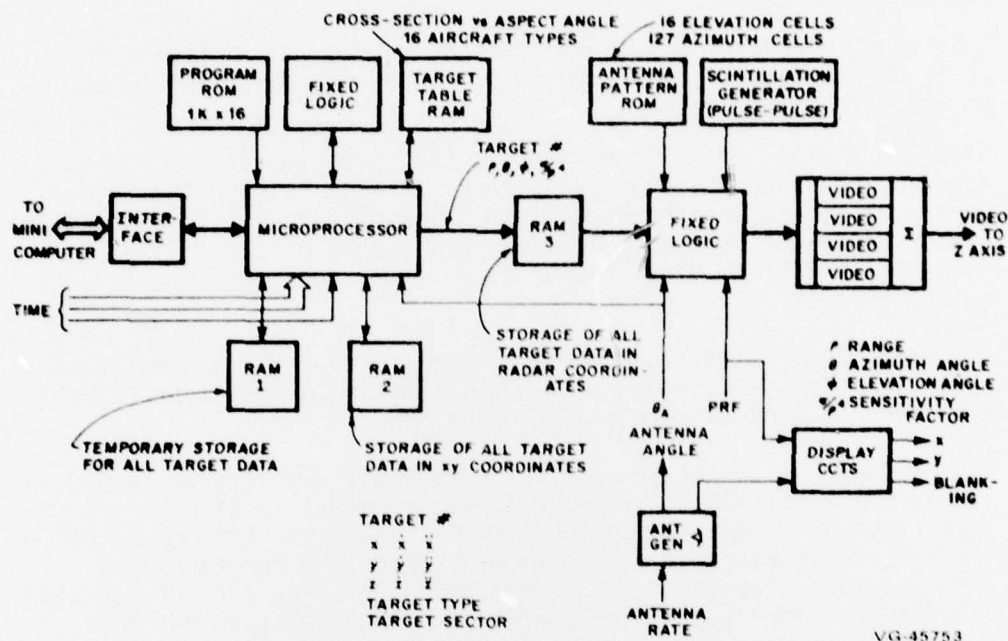


Figure 3-2. Target Generator Functional Block Diagram

The data stored in RAM₃ (target coordinates in $\rho\theta$ form) is fed to the succeeding circuits on a sector-by-sector basis. The ρ data is fed through the hardware logic to control the timing of a video pulse generated to simulate the target. Other characteristics stored in RAM₃ (θ , target bearing; ϕ , target elevation; and $\frac{\sigma}{\rho^4}$, a sensitivity factor) are combined with the instantaneous antenna angle and an antenna pattern ROM to define the proper signal amplitude to be generated by the simulator. A pulse-to-pulse scintillation factor is also incorporated into this function.

The output of the fixed logic is a series of digital words which define the relative time (range) and amplitude of the video pulses to be generated in response to a particular radar trigger pulse. The equipment built under project 9490 employs one assembly of 4 video generators and thus, up to 4 responses per transmitter pulse are possible. Expansion of the video generation capability would be in sub-modules with 4 video generator channels in each sub-module.

The video generator assemblies are of common design utilizing straightforward hardware techniques, and their output is summed before being fed out as a video signal for use in the PPI display.

The Target Generator Module also incorporates some circuits which are not properly part of the target generator function; they were located there for practical convenience. One circuit converts a pulse train defining antenna rate to a statement of antenna angle; the other circuits provide the x and y deflection signals for use in the PPI display.

Operations and Computations

The operations and computations implemented in the Target Generator Module are summarized in table 3-1, given below.

The operations are basically concerned with accepting inputs from the Supervisory Minicomputer; these define target positions, velocities, and parameters of the radar equation; from these inputs an appropriate set of video responses is determined and generated.

The computations relate to two major requirements: one, of maintaining a current statement of position on all targets, expressed in the xy domain; and the other, of providing radar coordinates for all required responses to a synthetic aircraft. While the updating in the xy domain is done once per second for all aircraft, the coordinate conversion is only done for aircraft about to be displayed on the PPI. A more detailed breakdown of the Target Generator computations is given in table 3-2.

OPERATIONS

- Accepts Inputs on A/C at Any Time, Including Inputs Ahead of Time.
- Accepts Inputs Defining P_{tx} , RCS, Radar Elev. (Initially and at Any Other Time).
- Controls Flow of Data to Video Generators.
- Responds to Interrogations on Status.

COMPUTATIONS

- Updates Target Vector for 200 A/C Each Second (Done in xyz domain).
- Coordinate Conversion on Active Targets (A/C).

Table 3-1. Operations and Computations in the Target Generator Module

POSITION UPDATE • DONE EVERY SECOND ON ALL 200 TARGETS

• SINCE $t = 1$

$$\left. \begin{aligned} v_2 &= v_1 + a \\ S_2 &= S_1 + v_1 + a/2 \end{aligned} \right\} \text{ FOR } x, y, z$$

COORDINATE
CONVERSION

• RANGE $r = (x^2 + y^2)^{1/2}$

• AZIMUTH $\theta = \tan^{-1}(x/y)$

• ELEVATION $\phi = \tan^{-1} \left[(1/r)(Z - r^2/2R_e) \right]$

R_e - Earth's radius

AIRCRAFT HEADING $\psi = \tan^{-1}(v_x/v_y)$

Arc tangent determined
from look-up tables

AIRCRAFT ASPECT ANGLE $|\psi - \theta|$

RECEIVED POWER
$$P_R = \frac{P_T G_T}{4 \pi R^2} \cdot \frac{\sigma}{4 \pi R^2} \cdot \frac{G_R \lambda^2}{4 \pi}$$

$$P_R = \frac{P_T \sigma G^2}{R^4} \cdot K_1$$

$$V_R = \frac{V_T \sqrt{\sigma} G}{R^2} \cdot K_2$$

$$\log V_R = \log V_T + \log \sqrt{\sigma} + \log G - 2 \log R + K_3$$

IN ADDITION, SCAN-SCAN (S_1) AND PULSE-PULSE (S_2)
SCINTILLATIONS ARE PROVIDED

$$\log V_R = (\log V_T + \log \sqrt{\sigma} + \log S_1 - 2 \log R + K_4)$$

$$+ (\log G + \log S_2 + K_5)$$

OUTPUT SIGNAL IS A VOLTAGE BASED ON THIS EQUATION

Table 3-2. Summary of Computations Done in the
Target Generator Module

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Microprocessor Timing

The timing associated with several critical operations done within the microprocessor network has been measured and the results are given in table 3-3.

xy coordinate update	= 32 ms/200 targets
	= 160 μ s/target
review 200 targets each sector	= 10.5 ms/review
coordinate conversion	= 1.3 ms/target

Table 3-3. Timing of Microprocessor Functions

The xy coordinate update is important because it is done for every target, every second. The reviewing of all the 200 possible targets is required each time the "antenna" enters a new sector (22.5 degrees wide) in order to establish which targets should have their current xy coordinates converted to radar coordinates. The time required for coordinate conversion is important because it is relatively long.

These operation times illustrate one of the design features intended for the simulator project, namely that if the system designer is given plenty of design space — hardware or software — then the design activity will proceed expeditiously and at low cost. It was intended that the microprocessor network be overdesigned, and these measured operation times indicate that, for an antenna rotation rate of 6 rpm and a field of 200 targets in the radar purview, the microprocessor spends only about 8% of its time making computations and exercising control. Sufficient margin was in fact provided that, with certain minor limitations, the system may be operated at rates as much as 8 times faster than real time. Once the initial design of the target generator had been established, the implementation proceeded without any changes being required and no difficulties in execution were encountered.

Design Features of Interest

Among the features of interest in the design of the Target Generator Module are the scintillation-radar-cross-section simulation and the mapping of antenna patterns in the antenna ROM.

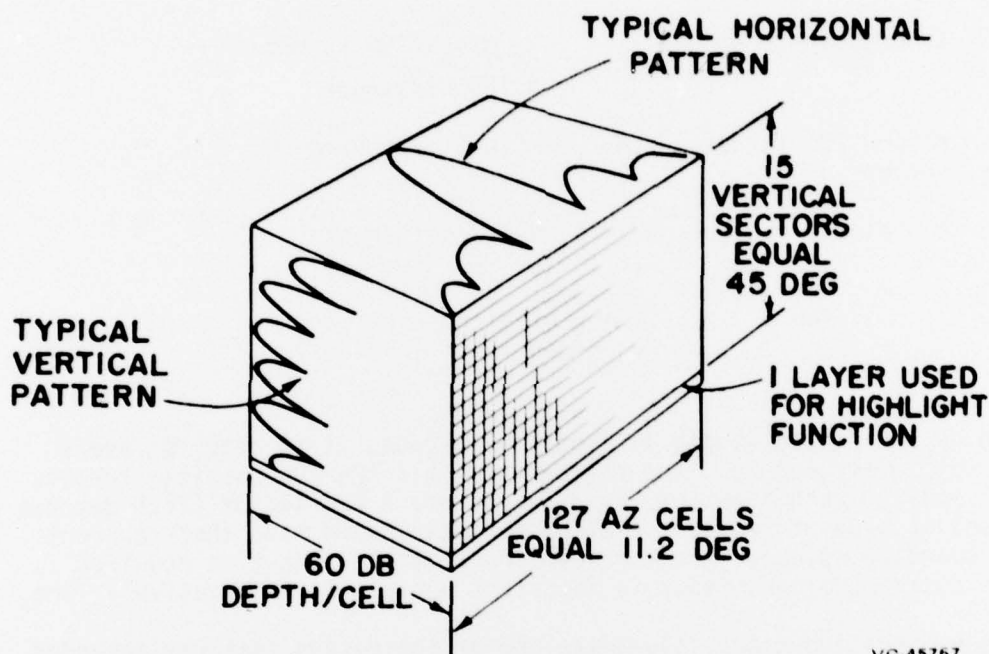


Figure 3-3. Antenna Pattern ROM

The radar treated as the standard to simulate is the AN/TPS-43, which is a 3-D radar. This radar utilizes several vertical beams and interpolation between them to determine the angle of elevation of the target of interest. Each of the vertical beams has an associated horizontal pattern, and these horizontal patterns are not necessarily all the same.

To accommodate this variability a 3-dimensional antenna ROM is employed in the Target Generator; this memory can, of course, be programmed to store any pattern set we wish to define within an azimuth gate of 11.2 degrees and an elevation space of zero to 45 degrees. In addition to defining antenna patterns, the antenna ROM reserves one layer to service a "highlight" function used to identify specified targets in the PPI display.

When an aircraft is continuously "painted" by a radar, the signals received by the radar are highly variable, this variability being referred to as scintillation. Beyond the scintillation effect one can also see a difference in the average value of the return signal as a function of the apparent aspect angle of the aircraft as viewed by the radar. These effects are illustrated in figure 3-4.

The Target Generator Module simulates the overall effect by permitting the assignment of a value of radar cross-section (RCS) to each of eight views of the aircraft (this sets the mean value for each octant), and to this mean value two scintillation values are added. Both scintillation values are defined by some form of quasi-random process; one value is varied on a scan-to-scan basis, the other on a pulse-to-pulse basis. Figure 3-5 illustrates the technique.

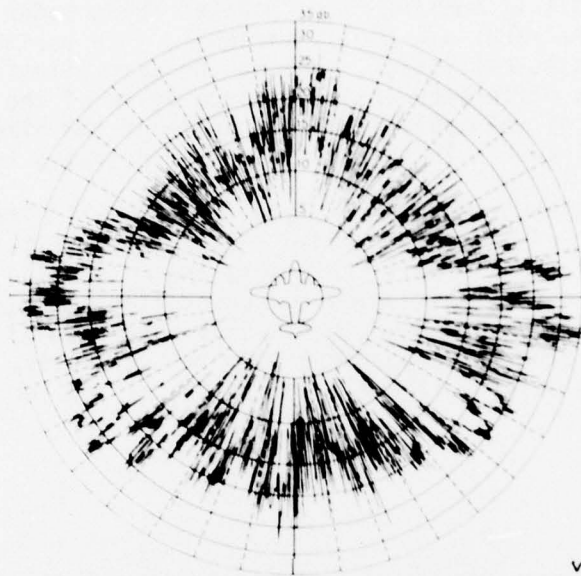
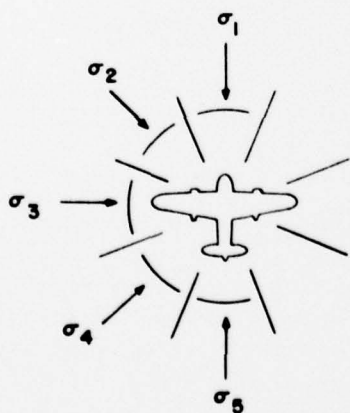


Figure 3-4. Typical Aircraft Response as a Function of Aspect Angle



- 5 MEAN VALUES OF RCS ARE USED
- SCINTILLATION ADDED TO THESE MEAN VALUES
- SCAN-SCAN SCINTILLATION 24 DB PEAK-PEAK
- PULSE-PULSE SCINTILLATION 12 DB PEAK-PEAK
- SCINTILLATION DERIVED FROM RANDOM NUMBERS

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Figure 3-5. Technique Used to Simulate Aircraft Response

SECTION IV

RESULTS

The photographs shown in this section illustrate the quality of the synthesized responses generated by the simulator. To those familiar with radar PPI displays the images appear a little empty since the simulation does not yet include the effects of clutter and weather. However, the character of the display responses to individual aircraft, the movement and scintillation associated with them, and the quite normal limited dynamic range shown in the display signal, all contribute to a very satisfactory acceptance by experienced observers. Two display samples are given in the following pages and they show results typical of the radar simulator.

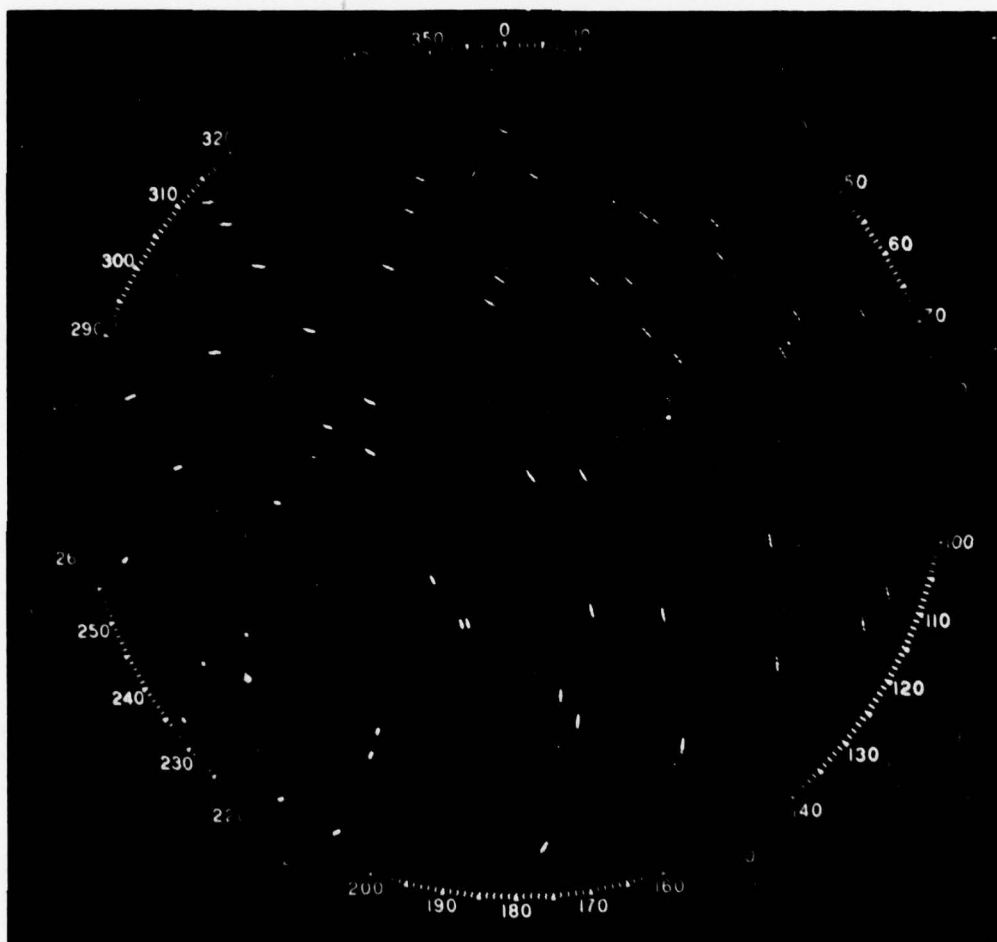


Figure 4-1. PPI Display, Sample 1

This photo shows the PPI display produced on an AN/UPA-35. The radar center is offset to emphasize the effect of range. This photo was made with a time lapse equal to one scan of the radar.

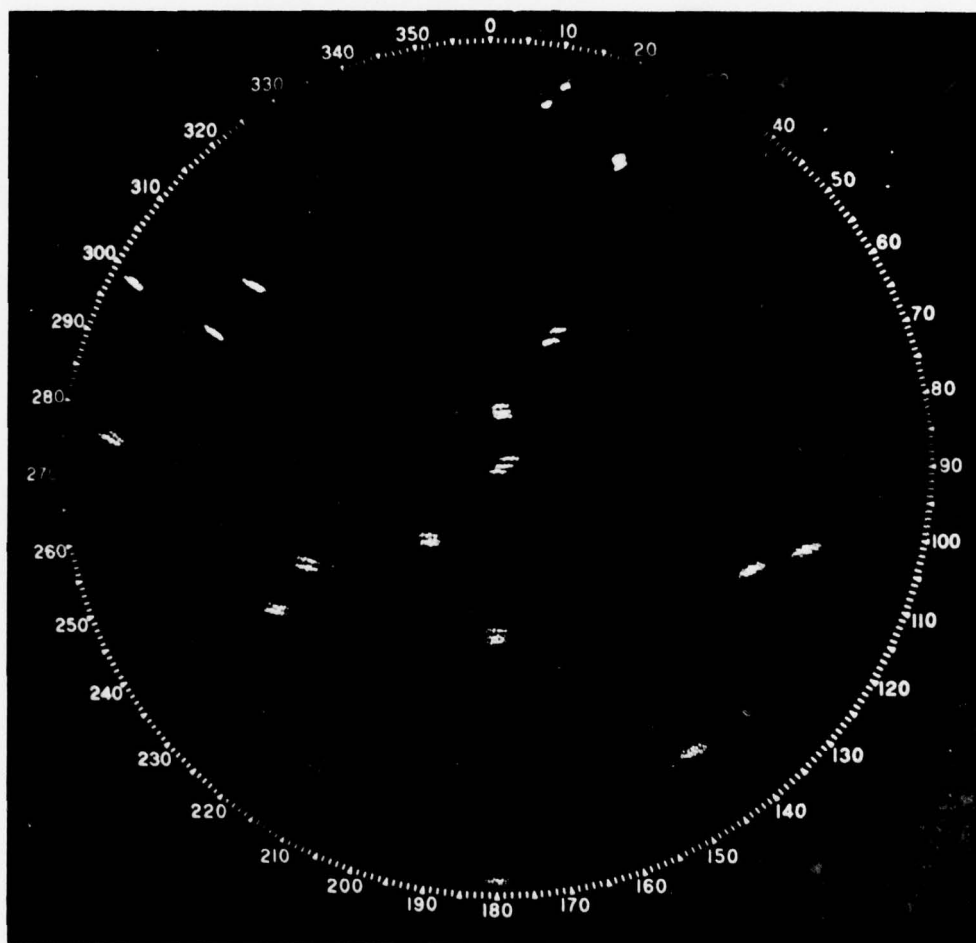


Figure 4-2. PPI Display, Sample 2

This photo is similar to figure 4-1, except that the range is reduced, and in addition the time lapse covered 3 scans of the radar; this distinguishes the targets according to their speed.

SECTION V

SUMMARY

The IR&D Project 9490 was established with several objectives:

- 1) to demonstrate our initial belief that distributed processing, coupled with the use of generous "design space," offers an opportunity to reduce system cost, reduce development time, and provide system flexibility.
- 2) to provide some experience in designing a system utilizing distributed processing techniques. We were interested in:
 - architecture and its impact on module design
 - possible problems in module-level and system-level testing
 - possible problems in system integration
 - the deliberately inefficient use of hardware, and its impact on the module design.
- 3) to build equipment which could be used as a base for further work in either distributed processing or simulators. To this end the equipment was required to have a design which would gracefully permit expansion into a full system.

Having now completed the work planned for Project 9490 we can assess the extent to which we have met these objectives.

We have found, as we expected, that when a designer is given plenty of design space — hardware or software — then the design can proceed in an orderly way with a minimum of deviation from an expeditious schedule. Distributed processing makes the concept practical since design space is only provided in the modules to the extent necessary to meet the individual module tasks. In contrast, providing generous "design space" for a centralized-processing approach requires provision on a total-system basis, which then becomes uneconomical.

With this project, the software design in the supervisory network, and both the hardware and software design in the target generator module, proceeded in a very straightforward manner. Once the system design and master-slave bus specifications were established, the design of the target generator module was implemented with no subsequent changes, nor were any difficulties in execution encountered. With the supervisory network, there were a number of changes made in the software as we recognized the need to perform more functions; however, the generous computation time and available memory, coupled with the use of FORTRAN, permitted modifications to be implemented quickly, easily, and without resort to clever programming.

The project experience led us to recognize that simply employing distributed processing is not sufficient to assure an economical design — one could otherwise devise a distributed-processing system no better than a centralized-processing system with its attendant problems in programming and complexity. What is important is that certain principles obtain, namely that the segregated tasks are self-contained as far as possible, and that communication among the modules be simple in nature and limited in rate. We also recognized with the simulator that the design should avoid bi-lateral communication among the modules, this being necessary to avoid contention for control of the module operation. This is much like "structured programming" which insists on only one entrance and only one exit.

With regard to testing, we found no problem at either the module level or the system level. For example, with the video generator module, testing was not difficult although a fully run test might have been more time consuming. Inputs to the module consist of simple digital words of standard form, and the output is a stream of pulses of specified amplitude and time location; all of these input/output elements are easy to observe and/or measure. We acknowledge that the testing was facilitated by a development aid designed into the module, and the simplicity in testing resulted somewhat from the simulator being a "small system", as distinct from some of the more complex networks found, for example, in C³ systems. A basic principle remains however — testing in a distributed-processing network is inherently easier than in a centralized-processing network.

System integration also proceeded in a straightforward manner; this was expected because the module tasks were well defined and segregated, and the communication between the modules was simple and very limited in nature. When system design incorporates these features, system integration is facilitated since there is a higher certainty that the system components will integrate compatibly.

Also, once the system is fully integrated, fault location is easier, since the operation of the various modules can be more easily observed and evaluated.

Our interest in the "inefficient use of hardware" reflected a conviction that, by essentially disregarding the quantity of hardware employed, one can make a reduction in development cost by reducing development labor. "Inefficient hardware" provides in part the "design space" referred to earlier. (The other contributor is the proper partitioning of the system problem). It was not necessary to evaluate alternate module designs since the use of "inefficient hardware" granted a high probability of success to the first-proposed and not critically optimized approach. With the target generator module the first-proposed approach was in fact successful.

The initial equipment we have built has certainly done all we expected of it, and in fact some of the fine-grain details as viewed on the PPI display are very pleasing. The equipment is very presentable in appearance, and is well fitted to our objectives in demonstrating the system capabilities.

To complete the summary we offer a commentary on the possible exploitations of this initial development. Several avenues merit consideration: further development on simulators of various types, further exploration into the design of distributed-processing networks, and the application of this approach to ECM/ECCM issues of interest to both radar and communication.

Further development on simulators might be directed towards completion of the existing system, or it could easily branch out to radars which use B-scan displays — precision approach radars and sector surveillance radars — or conical scan radars. Also, by utilizing an RF signal-generation version of the concept, one could simulate a variety of adversary situations and evaluate both ECM and ECCM techniques.

Since the system utilizes separate modules to simulate the various elements in a complex system, the concept is directly applicable to a communication system attempting to communicate in the presence of jamming. Simulation of such a network would be useful in exploring the benefits of anti-jam techniques, as well as the effectiveness of different jammers.

In summary, Project 9490 was established with several objectives; the work is now complete, and the objectives satisfied; opportunities to further exploit the work are also readily apparent.

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